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RESEARCH MEMORANDUM

EVALUATION OF ETHYL ETHER AS AN IGNITION AID FOR TURBOJET ENGINE FUELS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EVALUATION OF ETHYL ETHER AS AN IGNITION AID FOR TURBOJET ENGINE FUELS

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SUMMARY

An investigation was conducted to determine the effectiveness of ethyl ether as an ignition aid for low-volatility turbojet-engine fuels. The minimum spark energies required to ignite a single J33 combustor over a range of altitude inlet-air pressures and flow rates were obtained with a low-volatility reference fuel and with reference fuel blends containing (1) 10 percent ethyl ether, and (2) 10 percent normal pentane. Results indicated that the addition of ethyl ether improved the ignition characteristics of the low-volatility (1-lb Reid vapor pressure) fuel significantly; however, similar improvements in ignition were obtained with the addition of normal pentane in the same concentration. The improvement in ignition characteristics was, therefore, attributed solely to the increase in the front-end volatility characteristics of the reference fuel. The observed trend substantiates the results of previous investigations of the effect of fuel volatility on ignition characteristics.

INTRODUCTION

The ignition of turbojet engines at adverse conditions of high altitude and low temperature is of major concern to the operators of turbojet-powered aircraft. The variables that may affect ignition characteristics at any given operating condition include combustor design, ignition plug design, ignition energy, and fuel characteristics. The extent to which combustor design and ignition energy may be used to alleviate ignition difficulties is limited by the design requirements of other performance characteristics, and by weight and plug durability considerations, respectively. An increase in the front-end volatility characteristics of the fuel, which has been found to improve ignition characteristics, affects, detrimentally, altitude vapor loss and fuel-pumping characteristics. Therefore, other means of improving ignition characteristics of the turbojet engine are under consideration. Methods that may alleviate the problem in current operating aircraft without requiring redesign or modification of engine assemblies are of particular interest.

The data of reference 1 indicate that certain accelerator-type additives may improve the ignition characteristics of turbojet-engine

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fuels. More recently ethyl ether has been suggested as a fuel additive for a similar purpose. The objective of the investigation reported herein was to evaluate the effect of ethyl ether, added in a concentration of 10 percent to a low-volatility turbojet engine fuel, on the ignition characteristics of a single J33 turbojet combustor. The addition of ethyl ether reduced the front-end distillation temperature, which was found in reference 2 to improve ignition; therefore, a similar blend with the ethyl ether replaced by normal pentane was tested in order to ascertain the separate effect of additive composition. Ignition characteristics of the two blends and of the base fuel were evaluated in terms of the minimum spark energy required to ignite the combustor over a range of inlet total pressures and at two air-flow rates. Combustor-inlet fuel and air temperature was maintained constant at 10° F. 3096

Fuels

The reference fuel used for this investigation was a 1 pound Reid vapor pressure blend (NACA fuel 50-197) obtained by cutting volatile components from a JP-3 fuel stock. Physical properties of this fuel are presented in table I; the A.S.T.M. distillation temperature curve is presented in figure 1. The two test blends evaluated contained 10 percent (by volume) ethyl ether and 10 percent (by volume) normal pentane, respectively. Both additives were at least 98 percent pure. The A.S.T.M. distillation curves for these test blends are included in figure 1.

Apparatus and Test Procedure

The ignition characteristics of the fuel blends were evaluated in terms of the minimum spark energy required to ignite the combustor over a range of combustor inlet-air pressures and air-flow rates. A single tube J33 combustor (fig. 2), connected directly to the laboratory air supply and exhaust system, was used. The combustor was equipped with a small (10.5 gal/hr 80° spray-cone angle) fuel nozzle in order to maintain fuel atomization as nearly constant as possible. A production type F-99 ignition plug was used in conjunction with a variable-energy, constant-spark-rate (8 sparks/sec), capacitance-type ignition system (fig. 3). The spark-ignition system used in this investigation was, generally, similar to that used in reference 2. Spark energy was supplied at a voltage varying from 350 to 1400 volts, depending on the required energy. A high-voltage "trigger" circuit ionized the electrode gap for passage of the low-voltage, high-energy spark.

The minimum spark energy required for ignition was determined at pressures from atmospheric to the minimum at which ignition could be obtained. The investigation included two air-flow rates, 1.87 and 3.75 pounds per second per square foot (based on a combustor maximum cross-sectional area of 0.267 sq ft), which were representative of actual engine starting conditions. The inlet-air temperature was held constant at 10° F. The fuel was supplied to the combustor through a long copper coil immersed in the inlet-air ducting (fig. 2); inlet fuel and air temperatures were therefore similar.

At prescribed combustor inlet air conditions, the ignition system was energized and adjusted to a desired spark-energy level. Fuel was admitted to the combustor by opening a fuel throttle slowly until ignition occurred. Ignition was considered satisfactory if the flame filled the combustor and combustion continued after the spark was de-energized. By successively increasing or decreasing the selected value of spark energy, a minimum energy that would give repeated satisfactory ignition was determined.

A more complete description of the apparatus and procedure used in this investigation may be found in reference 2.

RESULTS

The minimum-ignition-energy requirements of the reference fuel and of the two reference fuel blends are presented in figure 4 as functions of combustor-inlet total pressure. Data are presented for the two air-flow rates representative of actual altitude starting conditions for turbojet engines. It is noted that as combustor-inlet pressure is reduced, or as the weight flow of air is increased, the required spark energy is increased. The data indicate that further increases in spark energy above about 3 joules per spark will not affect appreciably the low-pressure ignition limits of this combustor.

The ignition-energy requirements for the reference fuel blends containing either ethyl ether or normal pentane were identical, indicating no effect of the additive composition. The addition of either the paraffin or the ether did, however, reduce the ignition energy requirements of the reference fuel. Data of reference 2 indicate that minimum spark ignition energy is related to the A.S.T.M. 15-percent-evaporation temperature. It is noted in figure 1 that the two test blends had approximately equal 15-percent A.S.T.M. evaporation temperatures, which were below that of the reference fuel. The indications from reference 2 that Reid vapor pressures of fuels do not reflect their ignition characteristics is also substantiated by the data presented herein, since the two test blends having identical ignition characteristics had significantly different Reid vapor pressures, as noted in figure 1.

Figure 5 presents the relation between spark energy and the A.S.T.M. 15-percent-evaporation temperature developed in reference 2. The data of reference 2 are shown in figure 5 in addition to the data obtained in the present investigation. The curves represent different levels of severity of operating conditions, obtained from a correlation between spark energy and $V/\sqrt{P}$, where V is the combustor reference velocity, feet per second (based on combustor-inlet air density and combustor maximum cross-sectional area) and P is the combustor-inlet total pressure, inches of mercury absolute. It is noted that the slopes of the curves representing the present data agree with those from ref- 3096
erence 2. The reduction in the 15-percent A.S.T.M. evaporation temperature resulting from the addition of 10 percent ethyl ether, or 10 percent normal pentane, decreased the ignition energy required by approximately 50 percent at the most severe operating conditions $(V/\sqrt{P} = 21)$. When the data obtained in the present investigation are compared with similar data from reference 2, it is observed that significantly lower ignition energies were required in the present investigation. The decrease in required energy is attributed to the elimination of a 1/16-inch annular opening between the spark plug and the combustor liner. Reduced air velocities in the vicinity of the spark gap favored ignition. This result illustrates the fact that minor design features can have important effects on ignition characteristics in a turbojet combustor.

CONCLUDING REMARKS

An investigation was conducted to evaluate the effectiveness of ethyl ether as an ignition aid for low-volatility turbojet-engine fuels. The limited data obtained in one combustor indicated that the addition of 10 percent (by volume) of ethyl ether to a 1-pound Reid vapor pressure fuel decreased the ignition-energy requirements of the combustor significantly. However, similar results were obtained with the addition of normal pentane in the same concentration; thus, the beneficial effect of ethyl ether on ignition must be attributed to its high volatility rather than to its composition. The results obtained substantiate previous data relating spark ignition energy requirements to the A.S.T.M. 15 percent-evaporation temperature.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 28, 1953

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REFERENCES

1. Marshall, E. F.: Jet Propulsion Fuels. Prog. Rep. No. 29, Jan. 1 to Feb. 28, 1950, Res. and Dev. Dept., Sun Oil Co., Mar. 15, 1950. (USAF Contract No. W33-038-ac-9086.)

2. Foster, Hampton H., and Straight, David M.: Effect of Fuel Volatility Characteristics on Ignition-Energy Requirements in a Turbojet Combustor. NACA RM E52J21, 1953.

TABLE I. - PHYSICAL PROPERTIES OF LOW-VOLATILITY REFERENCE FUEL

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Fuel properties	NACA 50-197
A.S.T.M. distillation D86-46, °F	
Initial boiling point	201
Percentage evaporated	
5	242
10	271
20	297
30	315
40	333
50	349
60	363
70	381
80	404
90	443
Final boiling point	510
Specific gravity	0.781
Viscosity, centistokes at 100° F	1.05
Reid vapor pressure, lb/sq in.	1.0
Aromatics, percent by volume[a]	10.7

[a]Determined by silica gel method.

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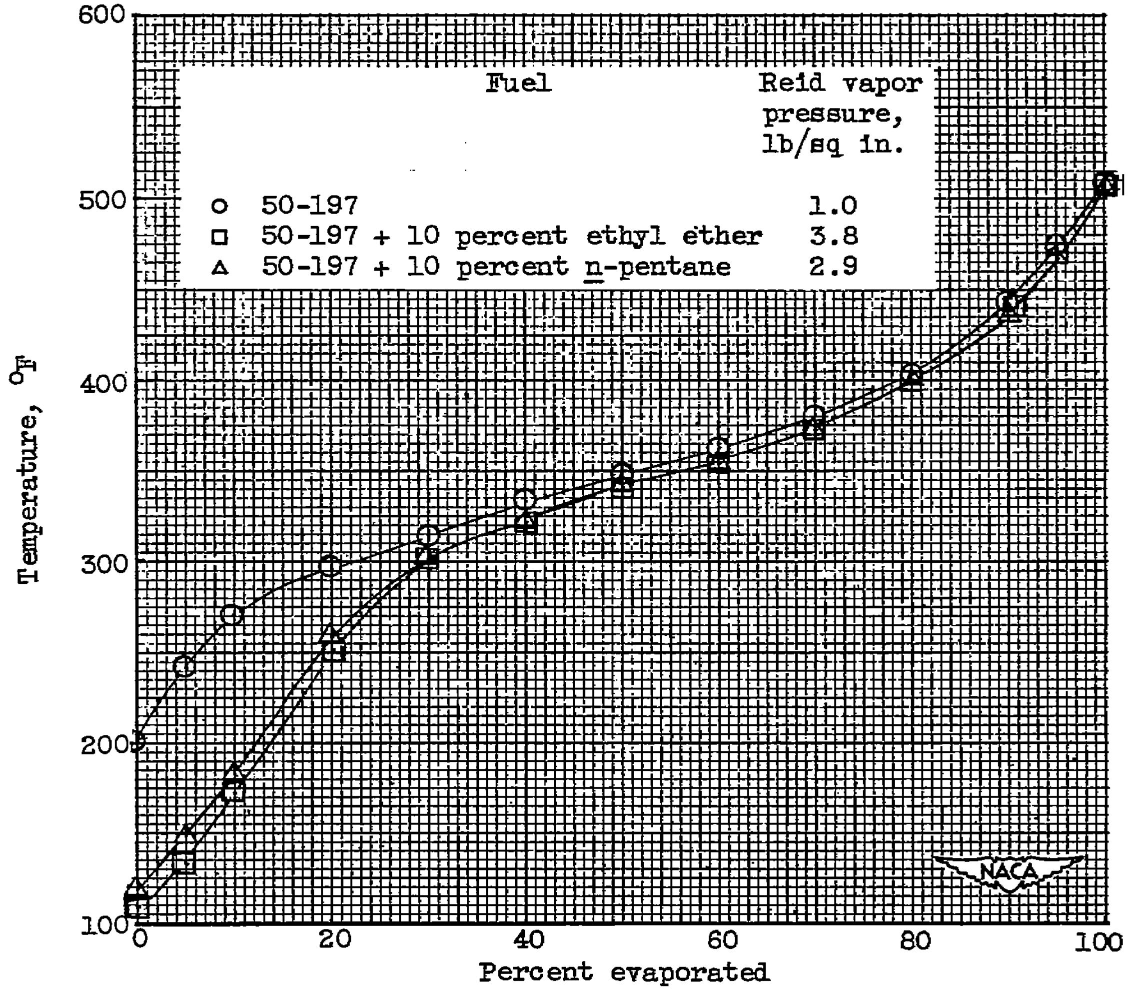

Figure 1. - Variation of distillation temperature with percentage evaporated for three fuel blends.

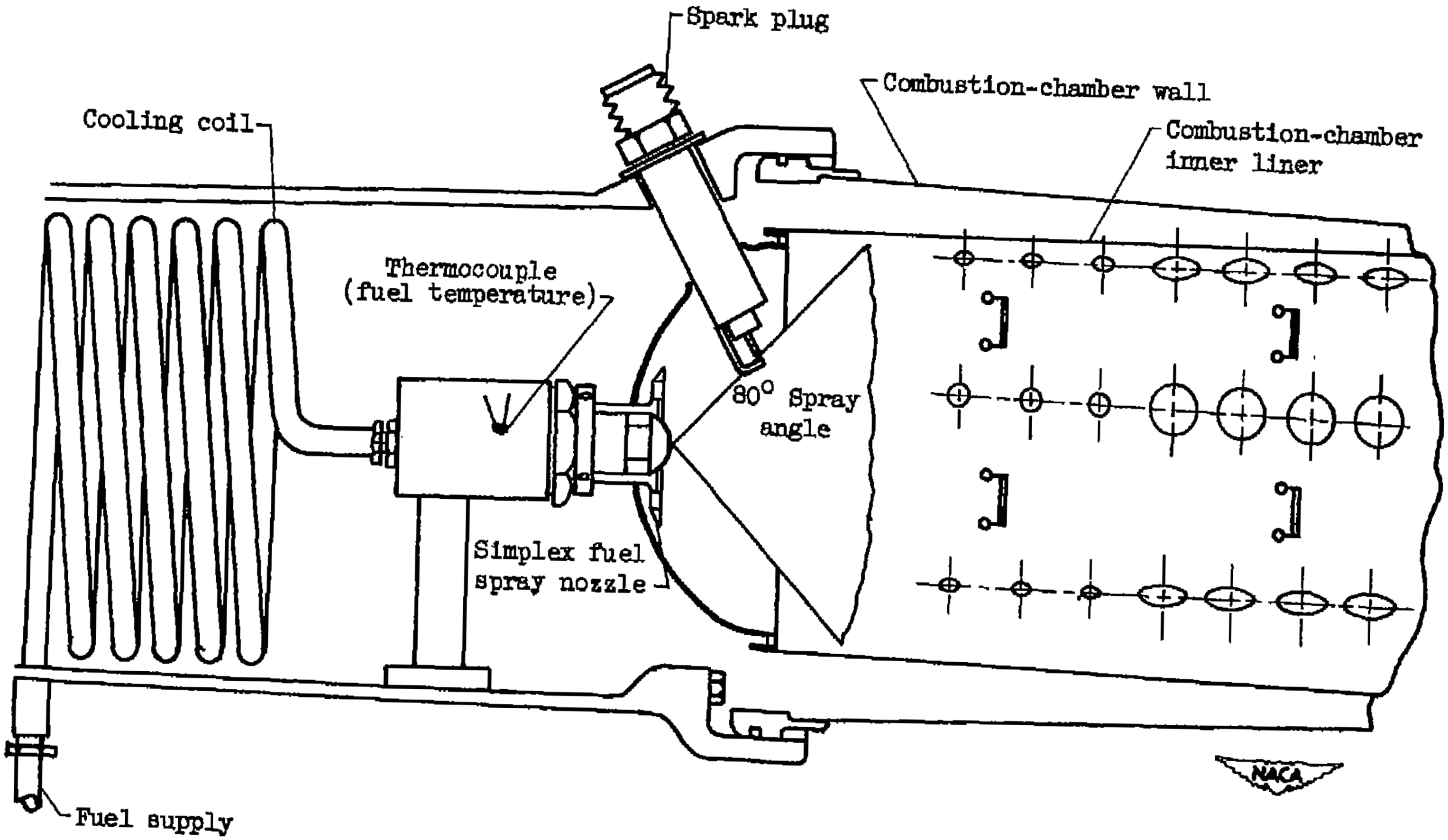

Figure 2. - Diagrammatic cross section of single tubular combustor.

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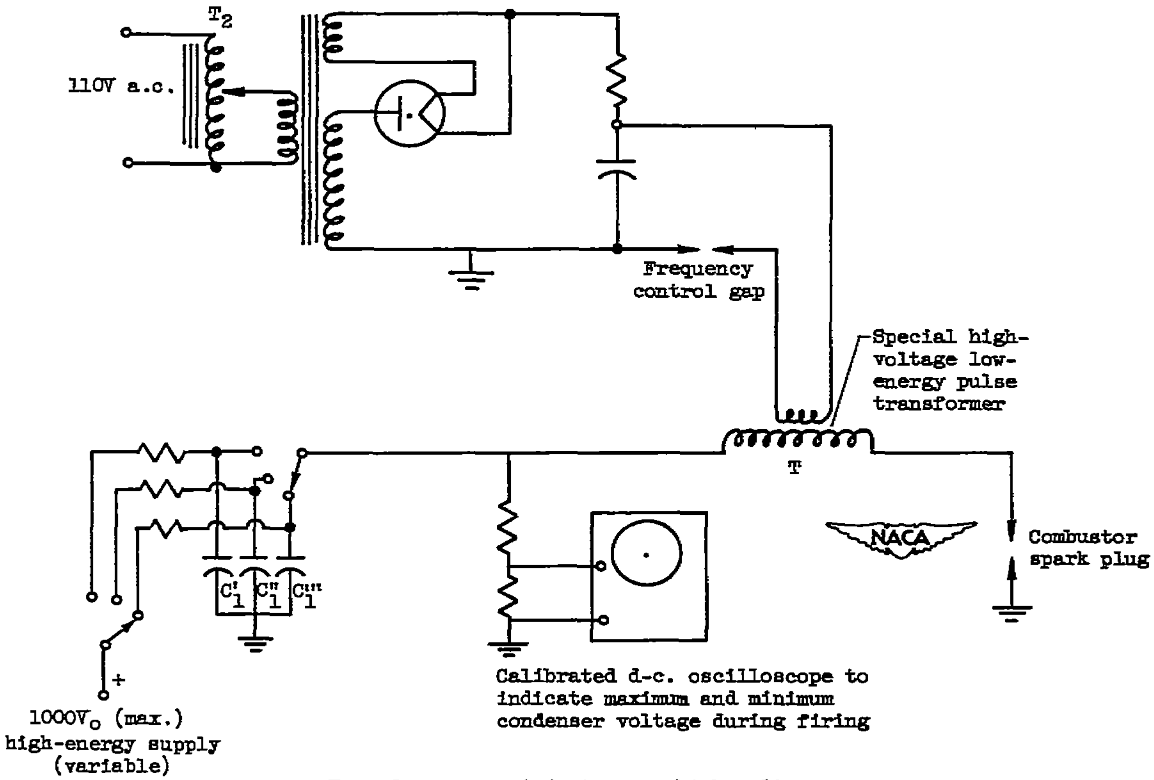

Transformer T injects very high voltage, very low energy pulses with a variable frequency determined by setting of T_2. Each high voltage pulse superimposed on the low voltage of C_1 ionizes the combustor spark plug gap and permits the relatively high energy of C_1 to be discharged through the combustor spark plug. C_1 consists of a bank of condensers any one of which can be selected to provide a specific known energy per spark.

Figure 3. - Simplified circuit diagram of spark ignition system.

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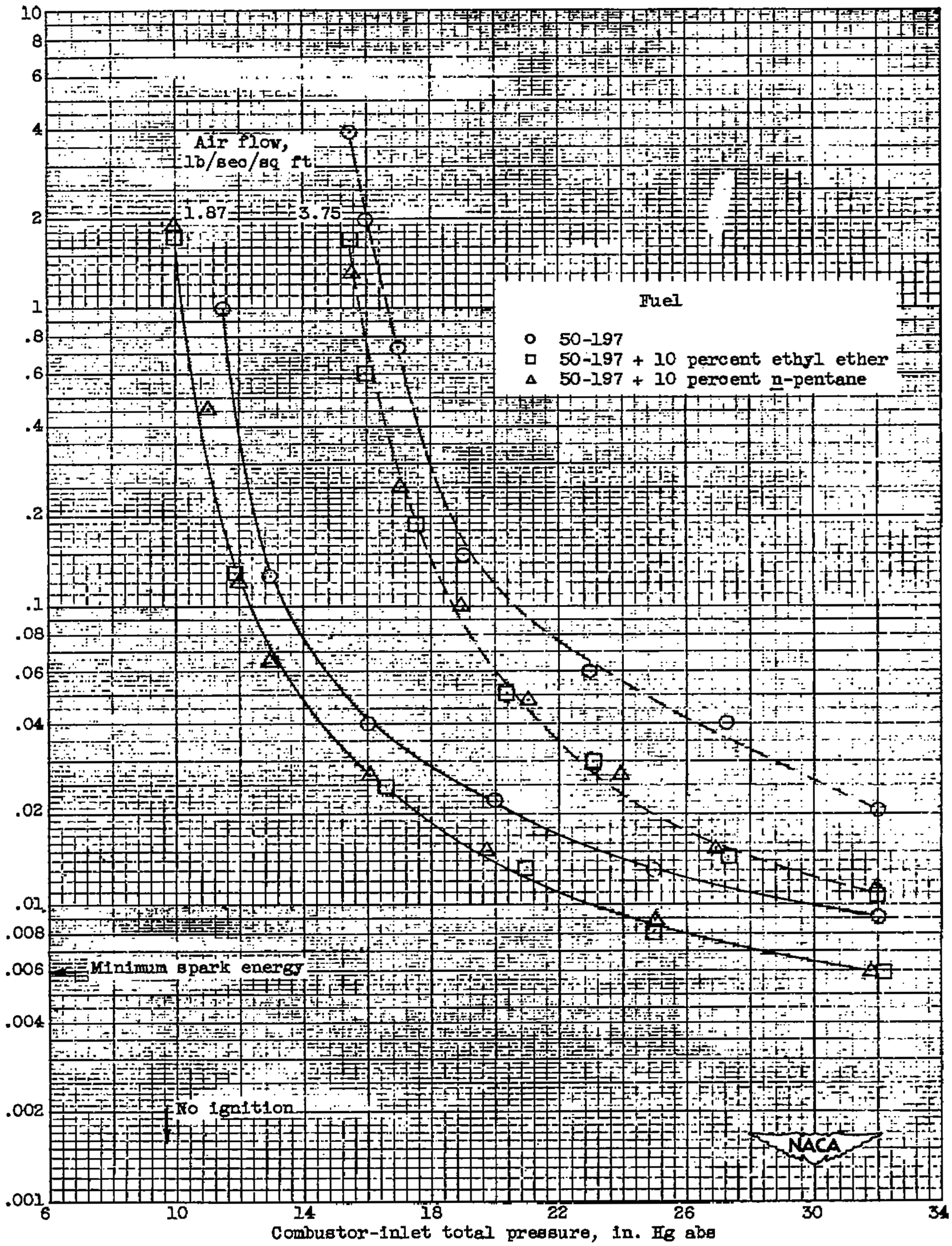

Figure 4. - Effect of combustor-inlet total pressure on minimum spark energy required for ignition of three fuel blends. Combustor-inlet air and fuel temperature, 10° F; J33 combustor.

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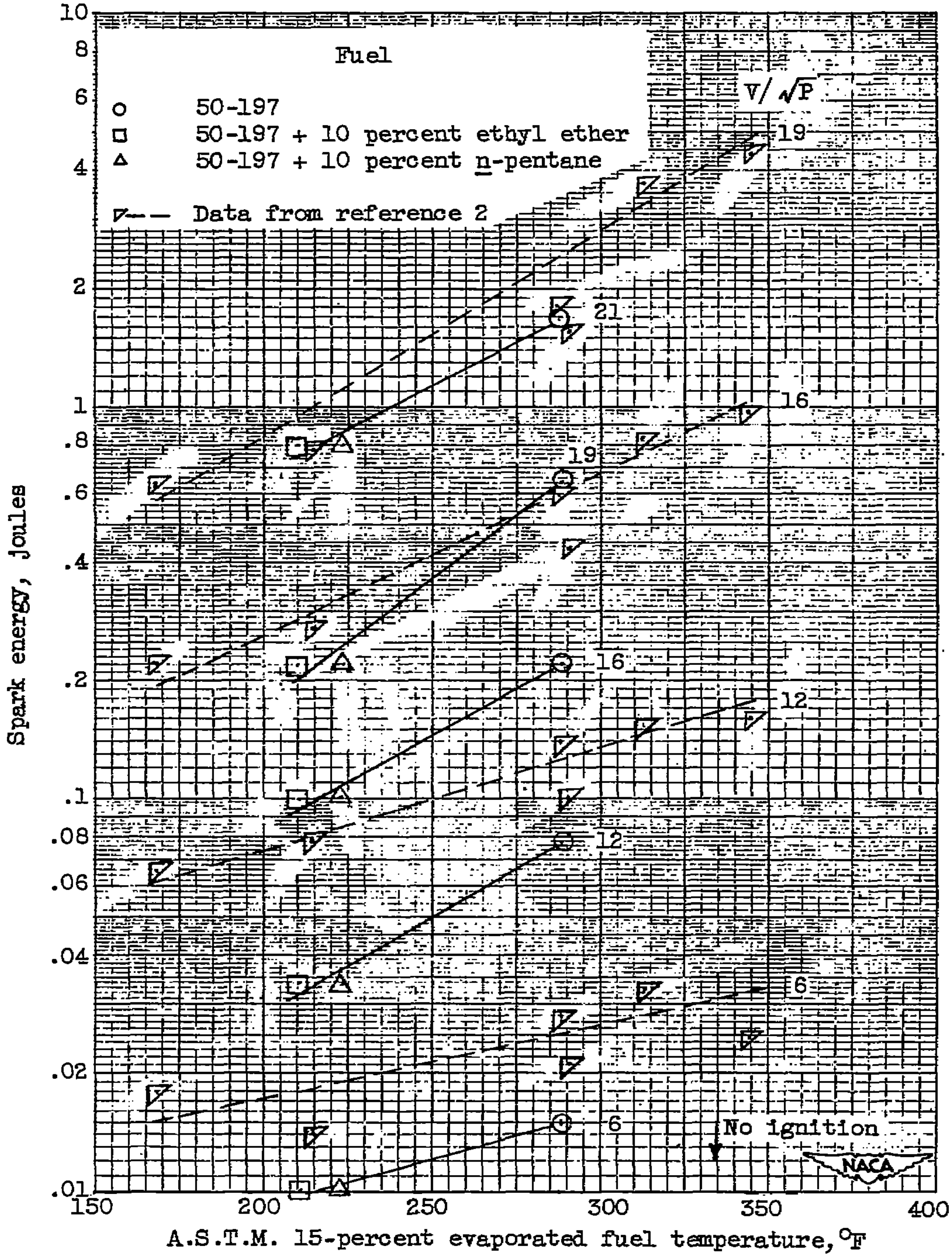

Figure 5. - Minimum spark energy required for ignition of three fuel blends as function of 15-percent evaporated fuel temperature at several values of $V/\sqrt{P}$. Combustor-inlet air and fuel temperature, 10° F.

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